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RESEARCH MEMORANDUM

INVESTIGATION OF A CHROMIUM PLUS ALUMINUM OXIDE METAL-CERAMIC BODY FOR POSSIBLE GAS TURBINE BLADE APPLICATION

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RESEARCH MEMORANDUM

INVESTIGATION OF A CHROMIUM PLUS ALUMINUM OXIDE METAL-CERAMIC BODY FOR POSSIBLE GAS-TURBINE-BLADE APPLICATION

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SUMMARY

A metal-ceramic composition containing approximately 80 percent chromium plus 20 percent aluminum oxide (Al_2O_3) by weight has been investigated for possible gas-turbine blade use. The results of modulus-of-rupture, thermal-shock, and blade-performance studies indicate that this material may have adequate thermal-shock resistance; however, the strength for the application appears marginal.

INTRODUCTION

Metal-ceramic compositions (cermets) have been investigated and found to be promising for gas-turbine-blade application (refs. 1 to 3); however, the emphasis has been on compositions containing a greater amount of ceramic and a lesser amount of metal constituent.

A metal-ceramic body containing principally metal with a lesser amount of ceramic was investigated at the NACA Lewis laboratory for possible gas-turbine-blade use. Although this material was not specifically intended for this use, its reported success in some high-temperature applications, as, for example, thermocouple protection tubes, has suggested its consideration for gas-turbine blades. Modulus-of-rupture, thermal-shock, and blade-performance studies were made.

APPARATUS AND PROCEDURE

Materials

The material investigated was furnished as test specimens and turbine blades by the Haynes Stellite Company. This material is designated by the manufacturer as Type LT-1 metal-ceramic. The composition as reported by a commercial analyst was 20.98 percent alumina, 78.90 percent chromium, and 0.14 percent iron, by weight. The modulus-of-rupture bars were 1/2 by 1/4 by 4 inches; the thermal-shock disks were 1/2 inch thick by 2 inches in diameter. The blade is illustrated in figure 1 and is identical in design to that used in previous investigations (refs. 2 and 3).

All specimens were radiographically inspected prior to evaluation and were considered satisfactory. The blade surfaces were also inspected by means of a penetrant-oil method. The results of this inspection are given in table I. 2966

Modulus-of-rupture evaluation. - The modulus-of-rupture apparatus consisted of a furnace incorporating a leverage system. The lever system allowed the application of a bending moment to a specimen held at temperature. The specimen was supported on two knife edges, 2 inches apart, and was loaded at the center through a third opposing knife edge. The apparatus and procedure are discussed in greater detail in reference 4. The specimen and knife edges were located in a chamber kept filled with argon.

Thermal-shock evaluation. - The thermal-shock apparatus consisted essentially of a furnace and an air-quench chamber. The evaluation consisted in quenching individual disks, 25 times from 1800° F, 25 times from 2000° F, 25 times from 2200° F, and 25 times from 2400° F at an air velocity of 265 feet per second or until failure occurred. If no failure occurred, this procedure was repeated at an air flow of 495 feet per second. The apparatus and procedure are discussed in greater detail in reference 2.

Turbine-blade evaluation. - The blade evaluation unit consisted essentially of a turbojet combustion chamber and a small gas turbine. The apparatus and procedure are discussed in detail in reference 1.

The operating cycle consisted in bringing the engine to idling speed in room-temperature air, initiating combustion, and increasing temperature slowly until the blade temperature was about 1450° F. The speed was then gradually increased until desired operating conditions were attained. The desired operating conditions, a speed of 22,850 rpm and a blade temperature of 1500° F, were chosen to duplicate the blade conditions which would be encountered in a current production turbojet engine.

Two cermet blades were run simultaneously in diametrically opposite positions in the turbine wheel (see fig. 2). In addition to the experimental blades, the wheel contained 10 control blades of AMS 5385 alloy. The remainder of the wheel was filled with metal blades the airfoils of which had been reduced to about 2/3 of their original length to decrease their operating stress. When a cermet blade failed, it was replaced with a new cermet blade and operation was continued.

The roots of the experimental blades were copper plated, or a nickel-plated perforated copper sheet was interposed between the blade base and the turbine wheel.

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RESULTS AND DISCUSSION

Modulus-of-Rupture Evaluation

The modulus-of-rupture results are shown in table II(a) and presented graphically in figure 3. These values may be compared (fig. 3) with those for 65 percent TiC + 20 percent Co + 15 percent (CbTaTi)C (table II(b) and ref. 2), two cermets that have been intensively studied; it is seen that the 80 percent Cr + 20 percent Al_2O_3 has poorer modulus-of-rupture strength. However, for a complete comparison it would be necessary to obtain relative strengths based on the long-time stress-rupture properties.

<u>Thermal-shock evaluation</u>. - The thermal-shock data are summarized in table III. Considerable variability is noted in that the specimens endured from 75 to 200 thermal-shock cycles. It is of interest to compare these results with those of other refractory materials that are being considered for turbine-blade use. Such a comparison is made in table IV. It can be noted that the Cr + Al_2O_3 cermet compares favorably with most of the TiC base materials. Since TiC base materials have been operated as gas-turbine blades for appreciable lengths of time (ref. 2) and appear to possess sufficient thermal-shock resistance, it may be hypothesized that the Cr + Al_2O_3 possesses adequate thermal shock resistance for turbine-blade applications.

The Cr + Al_2O_3 cermet is definitely superior in thermal shock to some of the other compositions studied. These include

100 percent ZrB_2
97.5 percent ZrB_2 + 2.5 percent B, sintered virgin powder
97.5 percent ZrB_2 + 2.5 percent B, hot-pressed recrushed powder
92.5 percent ZrB_2 + 2.5 percent B, hot-pressed virgin powder
TiB_2 plus B_4C
$MoSi_2$

No serious oxidation was noted during the present tests. Except for specimen number 1, slight oxides formed which were either green or dull gray. Specimen number 1 had a heavier dull gray scale.

Blade evaluation. - The turbine operating speed used in this investigation was chosen to yield the same cermet airfoil stress that would be encountered were this blade to be run in a current production engine.

Considerable care was exercised in handling the cermet blades and in engine testing. The blade temperature was gradually increased so as to minimize thermal shock. The maximum stress (i.e., maximum speed) was applied to the blades only after they were heated to a high temperature where they would be more resistant to mechanical shock. Cut-off metal blades were used to minimize the possibility of metal blade failure and possible cermet blade damage by a fragment. A soft cushioning material was used about the cermet blade roots to minimize any stress concentration. 2966

All the blades failed in the range of 18,000 to 20,000 rpm during the approach to 22,850 rpm, and at a blade temperature of about 1450° F. The total time of operation was less than 5 minutes in each case. There were no metal blade failures. All the failures occurred in the base at the neck-roll junction. The wheel containing a failed Cr + Al_2O_3 blade is shown in figure 2. A more detailed view of a failed blade is shown in figure 4.

The failures did not appear to originate from the surface flaws noted during the preoperation inspection, and a study of the failure cross sections failed to reveal any internal flaws which may have caused the failures. The failures occurred in a short time and may be associated with the short-time strength of the material. The temperature at the failure zone was estimated to be 1200° F. The stress at the failure zone, at the time of failure and without considering stress-concentration factors, was approximately 12,000 pounds per square inch. From figure 3, the modulus-of-rupture strength is 26,000 pounds per square inch, at 1200° F. Assuming the tensile strength to be about one half the modulus-of-rupture strength (this assumption is widely accepted as valid for brittle materials), the maximum allowable stress in the root is 13,000 pounds per square inch. Hence, on this basis it appears that the material was operating very near its ultimate tensile strength.

SUMMARY OF RESULTS

The following results were obtained on investigation of a cermet containing 80 percent chromium and 20 percent alumina:

1. The material has a modulus-of-rupture strength of 46,000, 23,000, 17,500, and 7500 pounds per square inch at room temperature, 1420°, 1800°, and 2200° F, respectively.

2. The material was able to survive as many as 100 thermal-shock cycles from temperatures as high as 2400° F at a quench-air-velocity of 265 feet per second and, in addition, as many as 100 thermal-shock cycles from as high as 2400° F with a quench-air velocity of 495 feet per second; this thermal-shock resistance appears adequate for turbine-blade use.

3. All the cermet blades failed in the base during the approach to operating conditions. It would appear that this material has marginal strength for turbine-blade application.

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Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 9, 1953

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4. Deutsch, George C., Repko, Andrew J., and Lidman, William G.: Elevated-Temperature Properties of Several Titanium Carbine Base Ceramals. NACA TN 1915, 1949.

5. Anon.: Alloy Castings, Precision Investment, Corrosion, and Heat Resistant. AMS 5385, SAE, Sept., 1947.

TABLE I. - RESULTS OF PREOPERATION PENETRANT-OIL SURFACE

INSPECTION OF TURBINE BLADES

Blade number	Root	Airfoil
1	Moderate surface porosity	Slight surface porosity
2	Considerable surface porosity	Considerable surface porosity
3	Surface fold	Good
4	Good	Slight surface porosity
5	Good	Good
6	Pin holes	Slight surface porosity

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TABLE II. - MODULUS-OF-RUPTURE RESULTS

(a) Chromium plus alumina.

[2.0-in. span loaded at 2000 psi/min]

Specimen number	Temperature, °F	Modulus-of-rupture strength, psi
1	80	46,000
2	1420	23,000
3	1800	17,500
4	2200	7,500

(b) Modified titanium carbide base cermets.

[3.5-in. span loaded at 2000 psi/min; ref. 2.]

65 percent TiC + 20 percent Co + 15 percent (CbTaTi)C				65 percent TiC + 20 percent Ni + 15 percent (CbTaTi)C			
Modulus-of-rupture strength, psi, at -							
1800° F	2000° F	2200° F	2400° F	1800° F	2000° F	2200° F	2400° F
56,700	36,300	17,900	1000	47,900	24,600	9950	975

[redacted]

TABLE III. - SUMMARY OF RESULTS OF THERMAL SHOCK INVESTIGATION OF CHROMIUM PLUS ALUMINA CERMET

Specimen number	Air flow, 265 ft/sec				Air flow, 495 ft/sec				Total of cycles	Remarks
	Number of cycles at				Number of cycles at					
	1800° F	2000° F	2200° F	2400° F	1800° F	2000° F	2200° F	2400° F		
1	25	25	25	25	11	--	--	--	111	Cracked
2	25	25	25	25	6	--	--	--	106	Fractured
3	25	25	25	--	--	--	--	--	75	Cracked
4	25	25	25	25	25	25	8	--	158	Cracked
5	25	25	25	25	25	25	25	25	200	Cracked
6	25	25	25	25	25	25	16	--	166	Cracked
7	25	25	25	8	--	--	--	--	83	Fractured

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TABLE IV. - SUMMARY OF RESULTS OF PREVIOUS THERMAL SHOCK INVESTIGATIONS

[Air flows of 265 ft/sec, unless otherwise noted.]

Composition	Average total number of cycles at 1800°, 2000°, 2200°, and 2400° F	Remarks
65 percent TiC + 20 percent Co + 15 percent (CbTaTi)C	75	Ref. 2; air velocity of 495 ft/sec
65 percent Tic + 20 percent Ni + 15 percent (CbTaTi)C	78	Ref. 2; air velocity of 495 ft/sec
80 percent TiC + 20 percent Co	100	Ref. 2; air velocity of 495 ft/sec
100 percent ZrB_2	38	Ref. 3; virgin powder, hot pressed
97.5 percent ZrB_2 + 2.5 percent B	7	Ref. 3; virgin powder, sintered
97.5 percent ZrB_2 + 2.5 percent B	46	Ref. 3; recrushed powder, hot pressed
97.5 percent ZrB_2 + 2.5 percent B	88	Ref. 3; virgin powder, hot pressed
97.5 percent ZrB_2 + 2.5 percent B	81	Ref. 3; type of powder not specified, hot pressed, annealed
92.5 percent ZrB_2 + 7.5 percent B	29	Ref. 3; virgin powder, hot pressed
60 percent B_4C + 40 percent TiB_2	3	From previous work done at Lewis
$MoSi_2$	2	From previous work done at Lewis

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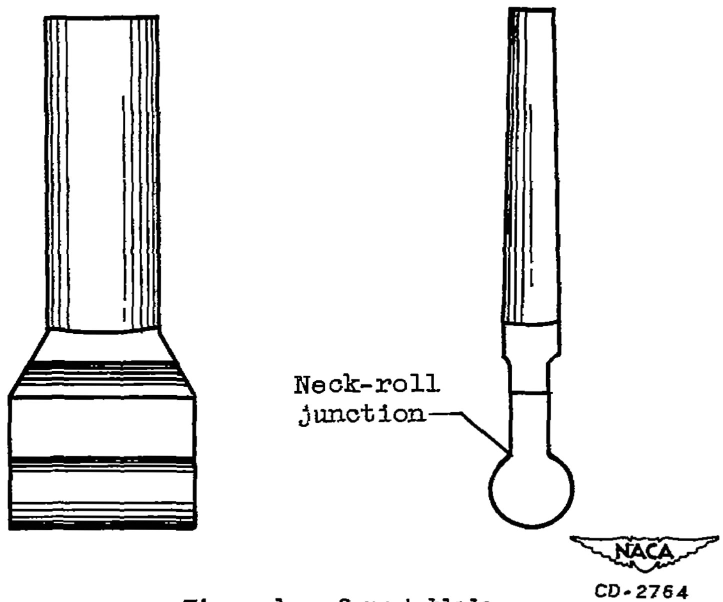

Figure 1. - Cermet blade.

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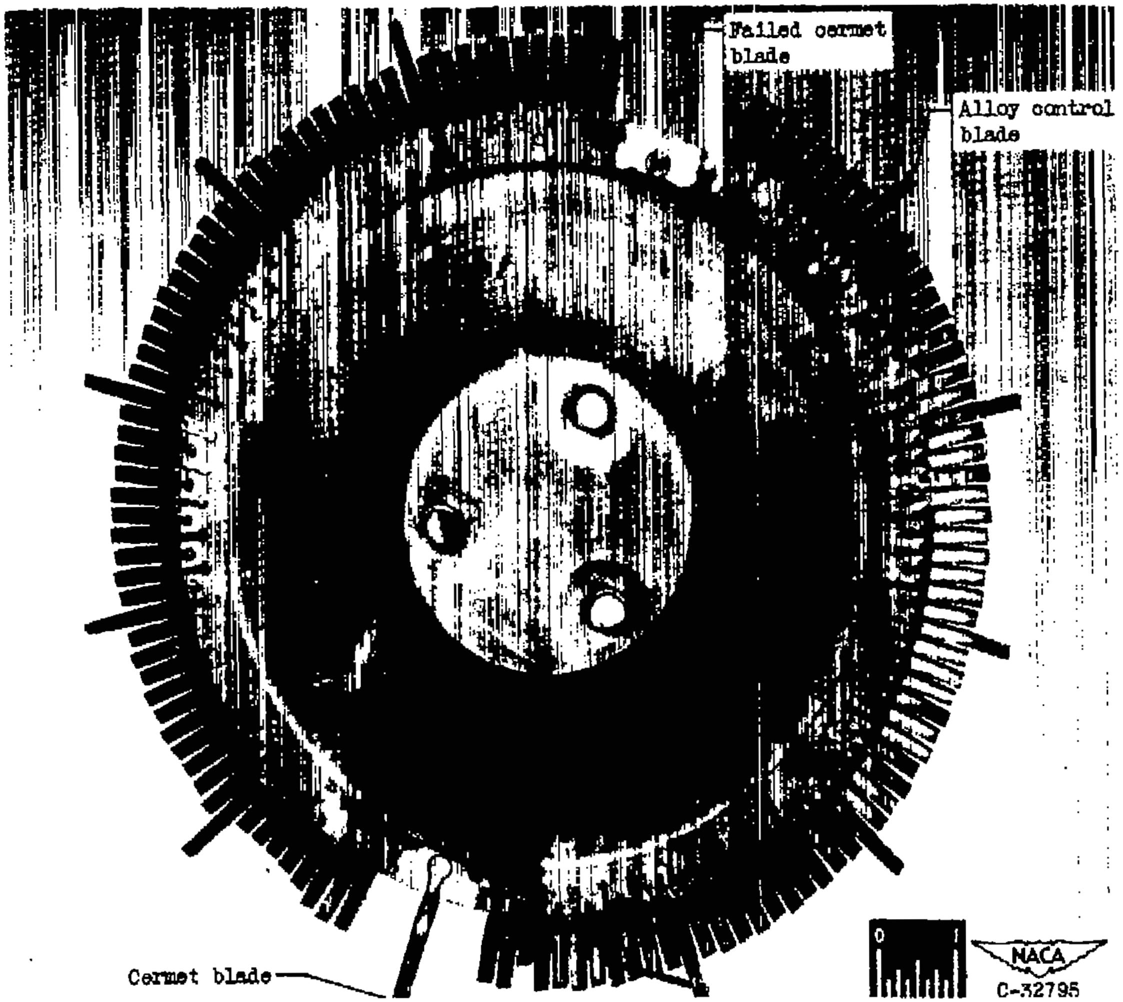

Figure 2. - Wheel after failure of a cermet blade.

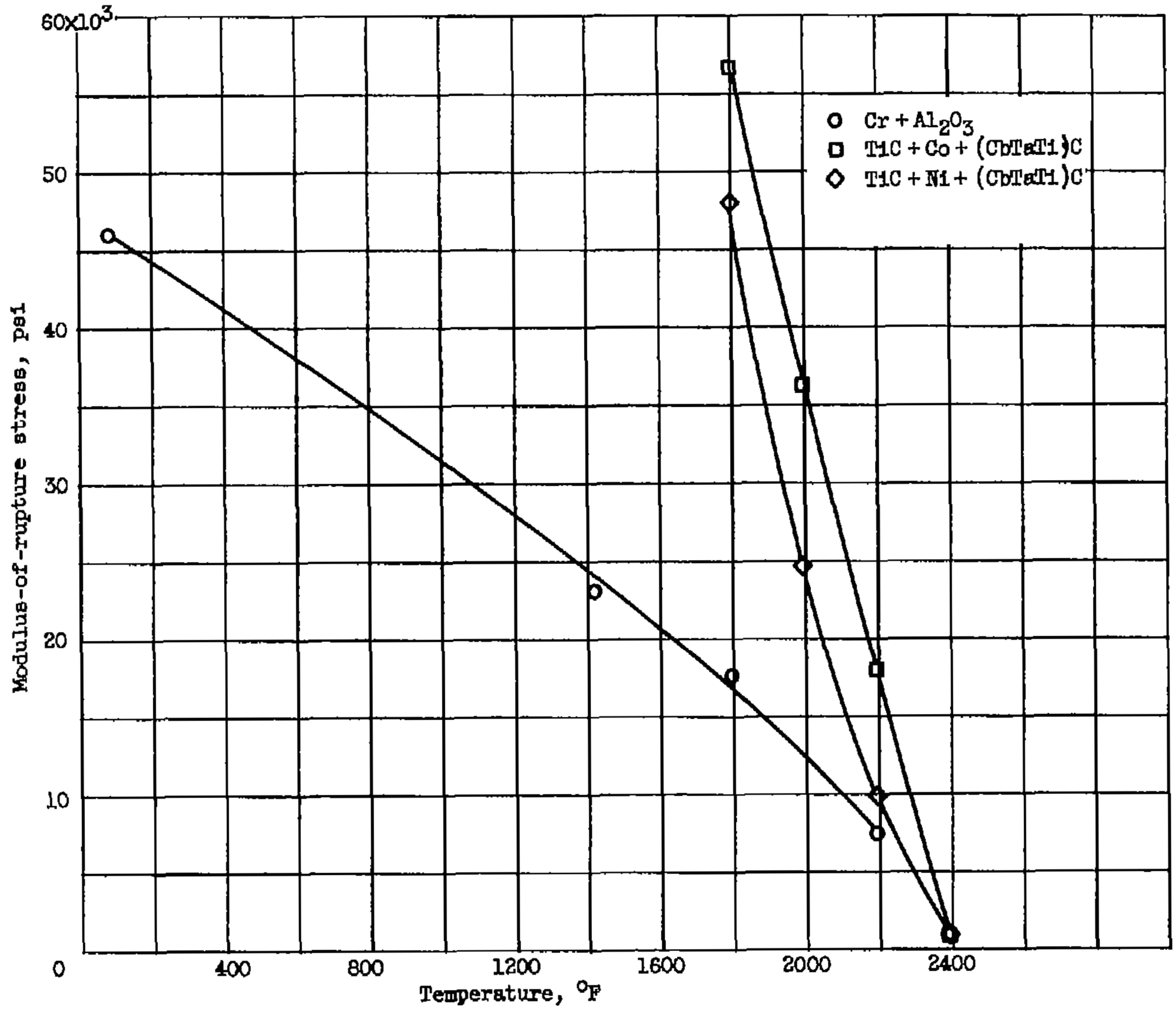

Figure 3. - Modulus-of-rupture stress against temperature. ($Cr + Al_2O_3$ specimens had 2-in. span; TiC specimens had 3.5-in. span. All were tested in argon atmosphere.)

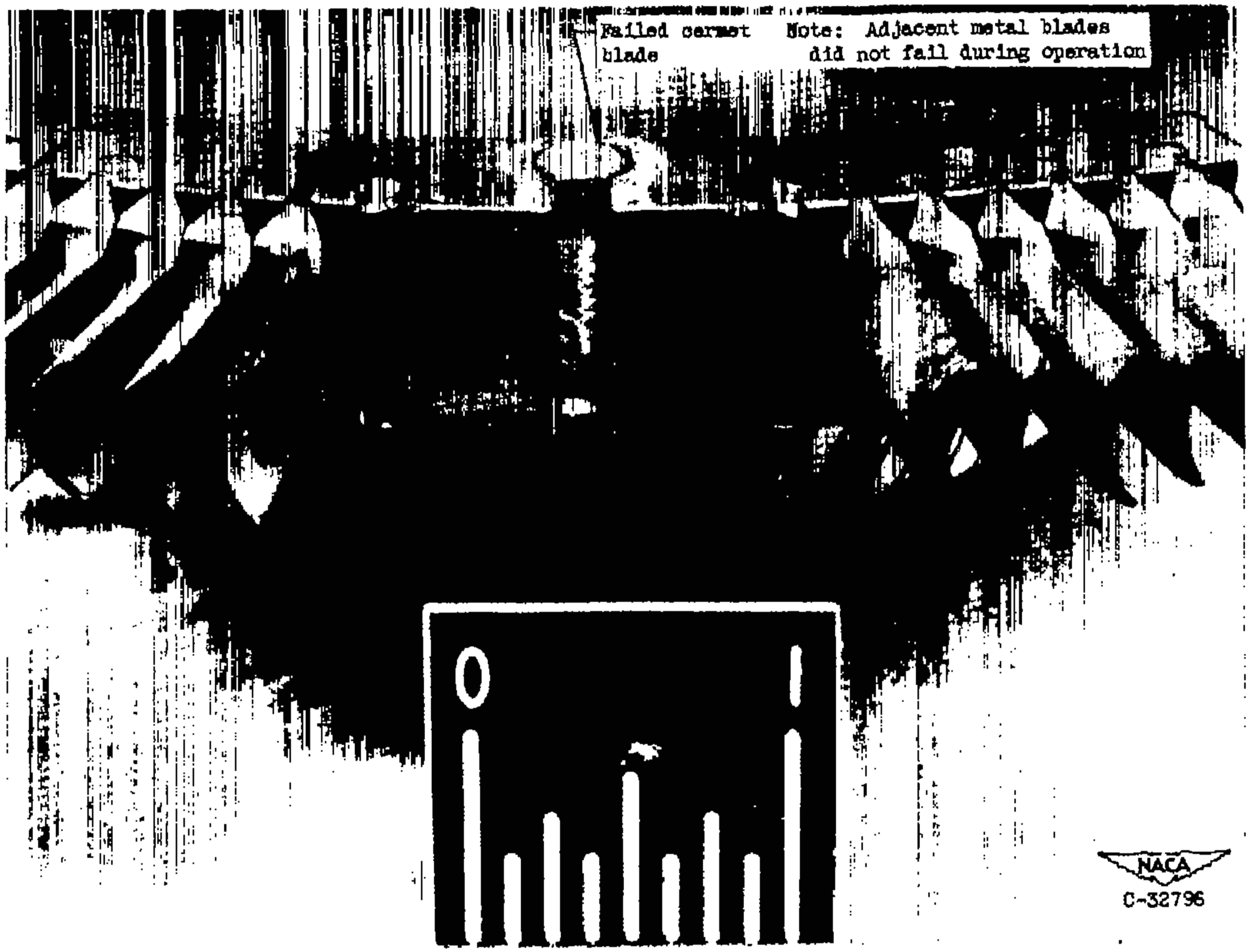

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Figure 4. - Close-up view of failed cermet blade.

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